Overpower Testing of TCR Fuel in TREAT

N. Woolstenhulme[1]*, D. Chapman[1], J. Fishler[1], C. Hill[1], K. Linton[2], M. Ramirez[1], D. Schappel[2], T. Smuin[1], K. Terrani[1], G. Vasudevamurthy[2], and D. Wachs[1]

[1]*Idaho National Laboratory, Idaho Falls, ID 83415*
[2]*Oak Ridge National Laboratory, Oak Ridge, TN 37831*
**Corresponding Author, Nicolas.Woolstenhulme@inl.gov*
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INTRODUCTION

The Transformational Challenge Reactor (TCR) is a reactor technology development project led by Oak Ridge National Laboratory. The project is focused on adoption of technology advancements, particularly advanced manufacturing, into nuclear application. The seminal goal of this project is a brief operation of a micro-scale reactor made with novel core materials. A rendering of the TCR core, vessel, and shielding structures can be seen in Figure 1 [1]. The TCR core is cooled by inert gas and comprised of various novel materials such as yttrium hydride moderator and additively manufactured structural components. The focus of this paper, however, is upon TCR's unique fuel form.

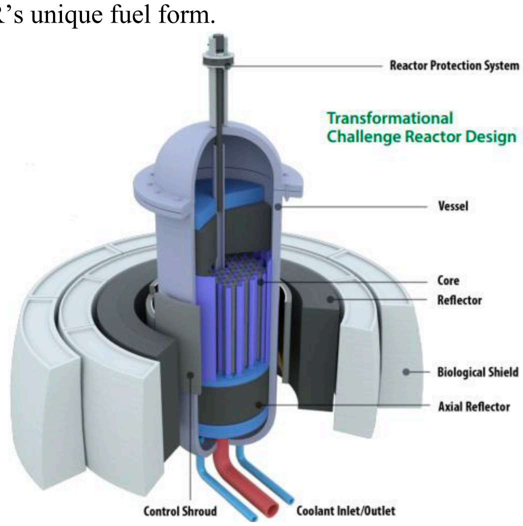

Figure 1: TCR Core Rendering

The TCR fuel design makes use of particle-based fuel kernel coated by a carbon buffer, inner pyrolytic graphite, silicon carbide (SiC), and outer pyrolytic graphite layers. These coatings comprise the typical Tristructural Isotropic (TRISO) fuel form, except that in the TCR design the fuel kernel diameter is increased to 800 μm and made from uranium mononitride (UN). An open top canister is prepared by powder bed 3D printing SiC by binder jet followed by Chemical Vapor Infiltration (CVI) to achieve monolithic SiC. The UN-TRISO fuel particles are poured into the canister and the assembly is treated again by CVI to infiltrate the pores with SiC. This method encapsulates the fuel particles in a fully ceramic matrix and avoids the compaction processes used in graphite-matrix TRISO design so that much higher packing fractions (~62%) can be achieved without coating damage [2]. Use of 3D printed canisters facilitates six-sided geometries for efficient core lattice stacking in hexagonal grids while the use of UN maximizes fissile loading further. This fuel design and manufacturing method creates an ideal system for small core designs based on TRISO fuel particles. An example of the TCR fuel block is shown in Figure 2.

Figure 2: Example of TCR Fuel Block

TEST DESCRIPTION

The Transient Reactor Test facility (TREAT) at the Idaho National Laboratory is an air-cooled material test reactor purposed for safety testing of nuclear fuel. TREAT's graphite-based core contains a dilute concentration of uranium oxide. This graphitic fuel design serves as a heat sink and moderator to enable safe and self-limiting nuclear power excursions with remarkable power maneuvering capability for transients ranging from milliseconds to a few minutes. TREAT was commissioned in the late 1950's, performed numerous tests on various fuel systems before suspending operations in 1994, and was successfully refurbished for resumption of fueled irradiations in 2018. These inaugural irradiations were performed on light water reactor rodlets using an inert gas environment irradiation capsule referred to as the Separate Effects Test Holder (SETH) [3].

Owing to the novelty and tremendous value potential of the TCR fuel form, a collaborative research effort was undertaken between Oak Ridge and Idaho National Laboratories to investigate the off-normal safety performance of this fuel. This test series was purposed to use TREAT as the neutron source while an adaptation of the SETH capsule, referred to as the Dry In-pile Fracture

Test series (DRIFT), was used to give the desired heat transfer conditions. Since the TCR fuel is composed entirely of low ductility materials with high melting temperatures, it was hypothesized that any limiting fuel behavior would more likely be manifest through thermomechanical fracture than from melting. Such a condition was postulated to arise from a hypothetical overpower event where an excursion in fission heating, combined with fuel cooling and other heat loss, would cause temperature and stress gradients exceeding the fracture strength of the fuel composite. The use of fission heating in TREAT was viewed as an important factor in these tests since direct particle internal heating would likely contribute to particle thermal expansion and heat transfer interactions with the matrix.

The DRIFT design makes use of a solid metal heat sink surrounding the specimen to absorb nuclear heat generated in the specimen. The DRIFT approach was studied previously for similar fuel fracture studies on uranium dioxide pellets and was found to pair well with TREAT's shaped power maneuvering abilities in achieving various specimen temperature gradients [4]. The DRIFT hardware also includes a small cable heater for elevating pre-transient temperature, various thermocouples, and fiber optics supporting both multispectral pyrometry for specimen surface temperature measurement and distributed temperature sensing for spatial mapping of the heat sink temperature response. See Figure 3.

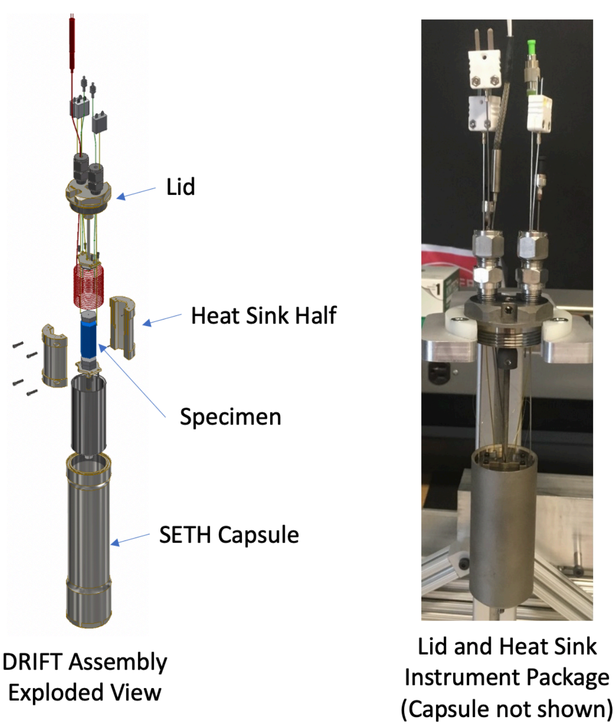

Figure 3: DRIFT Assembly Overview

Real time data from the DRIFT instrument package enables comparison of as-run temperature data to fuel performance modeling for enhanced understanding of test conditions. The heat sink holder is designed to split into two halves to facilitate disassembly and post transient examination of the specimen. While the original DRIFT design made use of a cylindrical cavity for housing fuel pellets, this design was modified slightly to support hexagonal TCR specimens. The geometry selected for these tests was a hexagonal specimen with a cylindrical cavity where the volume between the hexagonal and cylindrical wall is filled with fuel particles in the fashion described earlier. Fuel performance modeling via the BISON code has been undertaken and will be used to iterate, refine, and arrive upon the final transient test parameters. Irradiation of at least three capsules, each with one specimen, was planned as part of the initial test series. At the time this paper was written the specimens had been successfully produced by Oak Ridge National Laboratory and all hardware was under preparation for first irradiations in starting in Winter of 2021. See Figure 4 for an image of a fabricated fuel specimen.

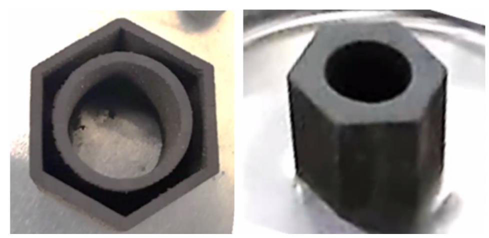

Figure 4: Example Test Specimen for TREAT

Since the TCR plant is only planned to operate for a few hours and accumulate negligible fission damage, the present TREAT studies will be adequate using fresh fuel specimens only. This approach also permits more rapid post transient examination using glovebox facilities rather than shielded hot cells. It is recommended that a future test series be undertaken where specimens achieve relevant burnup levels in other test reactors prior to safety research testing in TREAT. Such a test campaign would help demonstrate the full performance potential of the TCR fuel form.

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